Chapter 3

Visibility Trends

Introduction

The CAA requires EPA to protect visibility, or visual air quality, through a number of programs. These programs include the national visibility program under sections 169a and 169b of the Act, the Prevention of Significant Deterioration program for the review of potential impacts from new and modified sources, and the secondary NAAQS for PM_{10} and $PM_{2.5}$. The national visibility program established in 1980 requires the protection of visibility in 156 mandatory Federal Class I areas across the country (primarily national parks and wilderness areas). The CAA established as a national visibility goal, "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Federal Class I areas in which impairment results from manmade air pollution." The Act also calls for state programs to make "reasonable progress" toward the national goal.

In 1987, the IMPROVE visibility monitoring network was established as a cooperative effort between EPA, National Park Service, U.S. Forest Service, Bureau of Land Management, U.S. Fish & Wildlife Service, and state governments. The objectives of the network are to establish current conditions, to track progress toward the national visibility goal by documenting long-term trends, and to provide information for determining the types of pollutants and sources primarily responsible for visibility impairment. Chemical analysis of aerosol measurements provides ambient concentrations and associated light extinction for PM_{10}, $PM_{2.5}$, sulfates, nitrates, organic and elemental carbon, soil dust, and a number of other elements. The IMPROVE program has established protocols for aerosol, optical, and photographic monitoring methods, and these methods are employed at more than 70 Class I sites. The analyses presented in this chapter are based on data from the IMPROVE network which can be found on the Internet at ftp://alta_vista.cira.colostate.edu/IMPROVE.

This chapter evaluates data collected from 1988–1995 at 30 Class I areas in the IMPROVE network. To assess progress in preventing future impairment and remedying existing impairment, the chapter in some cases presents trends of the average "best," "worst," and "average" 20 percent of the data under consideration (i.e., "best" is the average of the 20 percent lowest values, also referred to as the 10^{th} percentile. Likewise, the terms, "worst" and "average" refer to an average of the upper 20 percent range—80 percent to 100 percent, and middle 20 percent range 40–60 percent, recorded annually). Figure 3-1 provides a visual illustration that contrasts visual air quality from the average best and worst conditions at Acadia, Great Smoky Mountains, and Grand Canyon national parks.[1]

Nature and Sources of the Problem

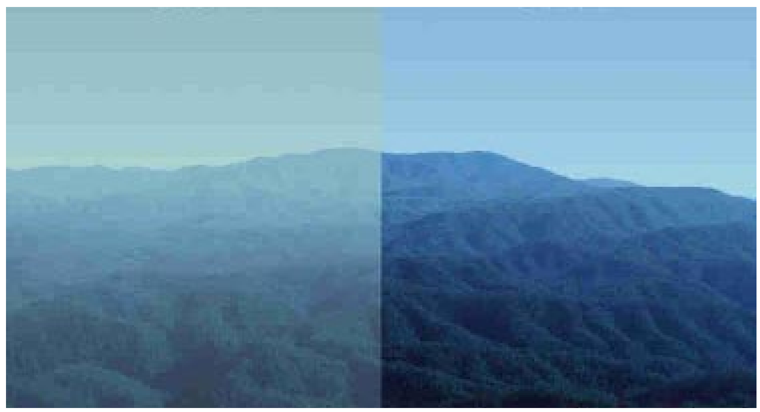
Visibility impairment occurs as a result of the scattering and absorption of light by particles and gases in the atmosphere. It is most simply described as the haze that obscures the clarity, color, texture, and form of what we see. The same particles linked to serious health and environmental effects (sulfates, nitrates, organic carbon, elemental carbon—commonly called soot—and soil dust) can also significantly affect our ability to see.

Both primary releases and secondary formation of particles contribute to visibility impairment. Primary particles, such as dust from roads and agricultural operations or elemental carbon from diesel and wood combustion, are emitted directly into the atmosphere. Secondary particles formed in the atmosphere from primary gaseous emissions include sulfate formed from sulfur dioxide emissions, nitrates from nitrogen oxide emissions, and organic carbon particles formed from hydrocarbon emissions. In the eastern United States, reduced visibility is mainly attributable to secondarily formed particles, particularly those less than a few micrometers in diameter. While secondarily formed particles still dominate in the West, primary emissions from sources such as woodsmoke contribute a larger percentage of the total particulate load than in the East. The only primary gaseous pollutant that directly reduces visibility is nitrogen dioxide.

In general, visibility conditions in rural Class I areas vary regionally across the United States. Rural areas in the East generally have higher levels of impairment than most remote sites in the West. Higher eastern levels are generally due to higher concentrations of anthropogenic pollution, higher estimated background levels of fine particles, and higher average relative humidity levels. Humidity can significantly increase the effect of pollution on visibility. Some particles, such as sulfates, accumulate water and grow in size, becoming more efficient at scattering light. Annual average relative humidity levels are 70–80 percent in the East as compared to 50–60 percent in the West. Poor summer visibility in the eastern United States is primarily the result of high sulfate concentrations combined with high humidity levels.

Visibility conditions are commonly expressed in terms of three mathematically related metrics: visual range, light extinction, and deciviews. Visual range is the maximum distance at which one can identify a black object against the horizon, and is typically described in miles or kilometers. Light extinction, inversely related to visual range, is the sum of light scattering and light absorption by particles and gases in the atmosphere. It is typically expressed in terms of inverse megameters (Mm^{-1}), with larger values representing poorer visibility. The IMPROVE network measures two parameters, light extinction using transmissometers, and light scattering using nephelometers. From these two parameters other parameters

Acadia National Park
Visual Range = 16 miles   Visual Range = 71 miles



Great Smoky Mountains National Park
Visual Range = 13 miles   Visual Range = 51 miles

Grand Canyon National Park
Visual Range = 60 miles   Visual Range = 124 miles

Figure 3-1. Range of best and worst conditions at Acadia, Great Smoky Mountains, and Grand Canyon national parks, 1992–1995.

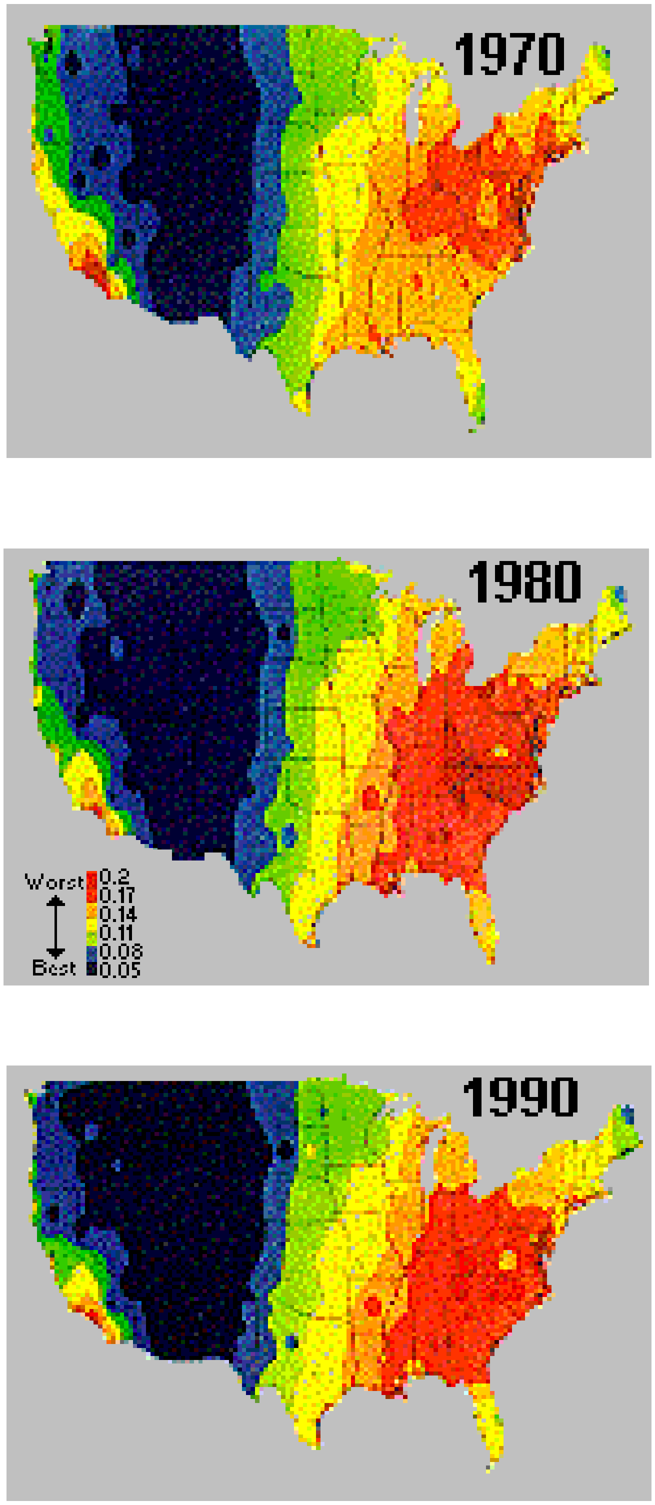


Figure 3-2. Long-term trend for 75th percentile light extinction coefficient from airport visual data (July–September).

such as visual range or deciviews may be calculated.

Equal changes in visual range and light extinction are not proportional to human perception, however. For example, a 5-mile change in visual range can be either very apparent or not perceptible, depending on the base line level of ambient pollution (see Figure 3-1). The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy, analogous to the decibel scale for sound. Under many scenic conditions, a change of one deciview is considered perceptible by the average person. A deciview of zero represents pristine conditions.

Long-Term Trends

Visibility impairment has been analyzed using visual range data collected since 1960 at 280 monitoring stations located at airports across the country. Trends in visibility impairment can be inferred from these long-term records of visual range. Figure 3-2 describes long-term U.S. visibility impairment trends derived from such data.[2] The maps show the amount of haze during the summer months of 1970, 1980, and 1990. The dark blue color represents the best visibility, and red represents the worst visibility. Overall, these maps show that summer visibility impairment in the eastern United States increased greatly between 1970 and 1980, and decreased slightly between 1980 and 1990. These trends follow overall trends in emissions of sulfur oxides during these periods.

Recent Trends in Rural Areas: 1988–1995

Aerosol and light extinction data have been collected for eight consecutive years (1988–1995) at 30 sites in the IMPROVE network (see Figure 3-3). Of

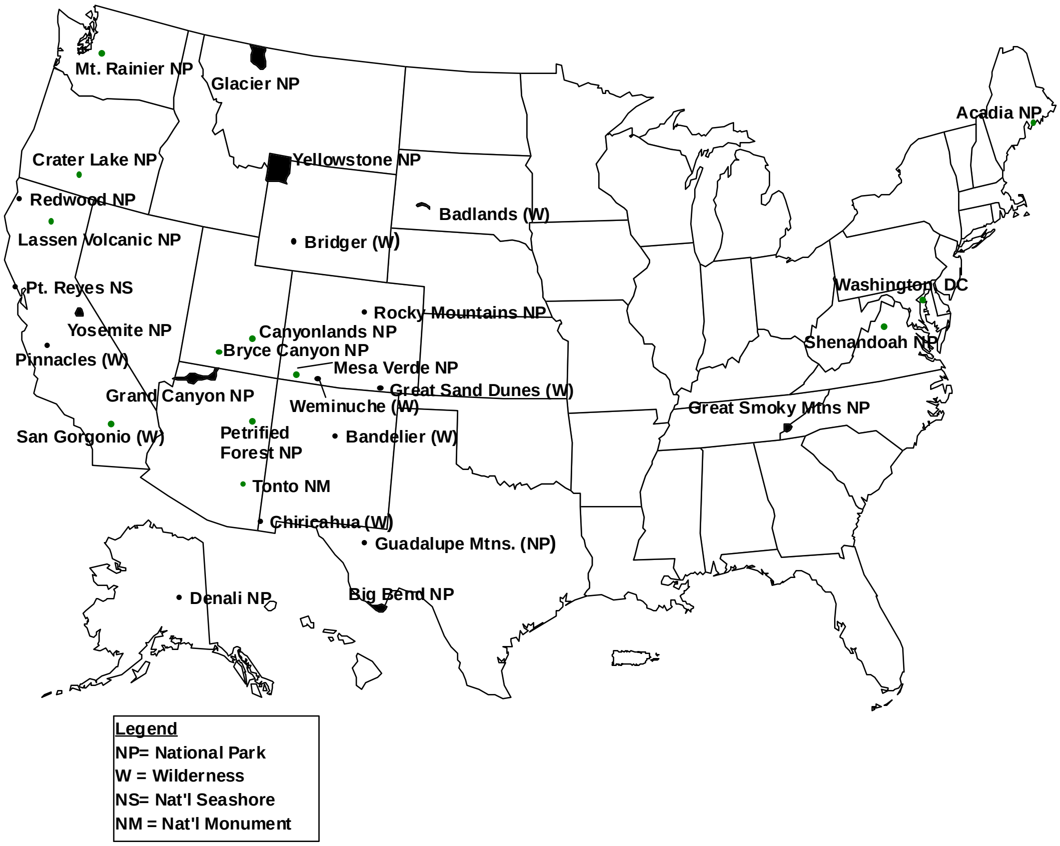


Figure 3-3. IMPROVE visibility monitoring network 30 sites with data for the period 1988–present.

these 30 sites, Washington, DC is the only urban location. The remaining 29 represent rural Class I areas: three are located in the East (Acadia National Park, Maine; Shenandoah National Park, Virginia; and Great Smoky Mountains National Park, Tennessee), and 26 are located in the West. Because of the significant regional variations in visibility conditions, this section does not look at aggregate national trends, but groups existing sites into eastern and western regions. As noted earlier, the values representing the "best" and "worst" days are presented in addition to median values. For the purposes of this report, these terms correspond to the 10th, 50th and 90th percentiles.

Regional Trends

Figures 3-4a and 3-4b illustrate eastern and western trends for total light extinction. These figures indicate that, in general, aerosol light extinction for the best days (10th percentile) and median days (50th percentile) showed downward trends over the eight-year period for both eastern and western regions, indicating overall improvement in visibility. Reductions of light extinction between 1988 and 1995 for the best and median days ranged from 9–20 percent in the east and 10–30 percent in the West. The East showed a degradation of visibility with a 6-percent increase in light extinction for the worst days (90^{th} percentile), whereas western sites, on the other hand, showed general improvement.

Figures 3-5 and 3-6 show eastern and western trends in light extinction due to sulfate and light extinction due to organic carbon. Light extinction due to organic carbon dropped significantly between 1988 and 1995 for the 10th, 50th, and 90th percentile values in both the eastern (24–47 percent) and western regions (30–52 percent). Sulfate light extinction, on the other hand, was much more variable in both regions. Seasonal averages for light extinction due to sulfate over the 1988–1995 time period generally increased in the summer. In the East, light extinction due to sulfate in 1995 shows a 21-percent increase from 1988 levels for the worst visibility days, but median sulfate extinction shows a 7-percent improvement for the same period, with lowest levels occurring in 1994 and 1995. In the West, it appears that sulfate extinction increased between 6–9 percent between 1988 and 1995 for the median and worst visibility days, although gradual improvements are seen after levels peaked in 1992. Note that the vertical scales for Figures 3-3 to 3-6 have been altered to better view trends, since light extinction due to sulfate is much greater in the East.

Figures 3-7a and 3-7b show the relative contribution to median (50th percentile) eastern and western aerosol light extinction, respectively, for the five principal constituents measured at IMPROVE sites. These graphs illustrate that sulfate, organic carbon, and elemental carbon are the largest contributors to aerosol light extinction, with sulfate playing a larger role in the East and West. Nationally, light extinction from sulfate, nitrate, and soil dust appear to have remained fairly constant over the eight-year period, while organic carbon and elemental carbon appear to be declining.

Class I Area Trends. IMPROVE data from 30 Class I area monitoring sites in place from 1988–1995 were analyzed using a nonparametric regression methodology described in Chapter 7, Metropolitan Area Trends. Trends are reported in Table A-12 according to their significance, upward or downward, or as not significant.

Table 3-1 summarizes the trends analysis performed on these 30 sites for total light extinction (expressed in deciviews), light extinction due to sulfate, and light extinction due to organic carbon. Because of the importance of tracking progress in the entire distribution of visibility conditions, trends in the 10th, 50th, and 90th percentile values were analyzed. No sites were found to have statistically significant upward trends for any of the parameters evaluated. Several sites, however, did have positive slopes for various parameters, indicating some degree of an upward trend.

On an annual average basis, about one-third have significant downward trends in deciviews. Only one site had a downward trend for sulfate, whereas close to 20 of the 30 sites have a downward trend for organic carbon.

Fewer sites were found to have significant trends in hazy day conditions than for the cleanest days. Only five sites showed significant downward trends in deciviews for the haziest days, whereas one-third to two-thirds of the sites showed significant trends for the cleanest days. Many more sites had significant downward trends in organic carbon light extinction than for sulfate light extinction.

Although the nonparametric analysis described above does not reveal any sites with significant upward trends in visibility impairment, a review of annual data plotted for each site shows several sites that should be monitored closely for gradual upward trends for either the best, median, or worst days. Table 3-2 lists those sites which may be of potential concern.

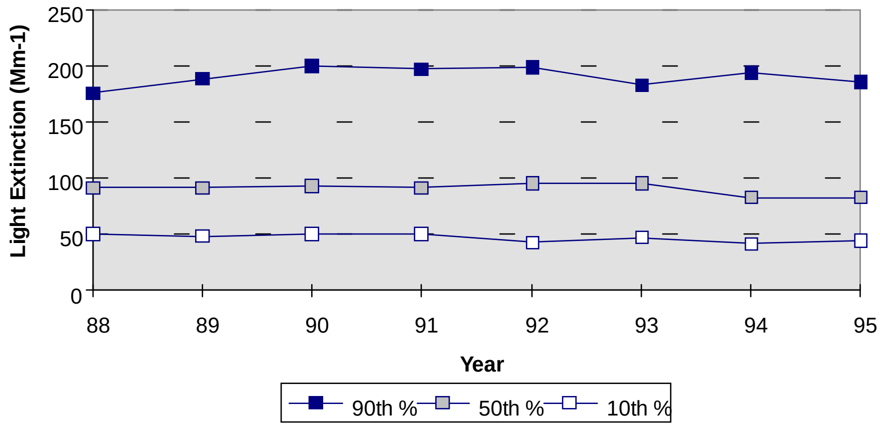


Figure 3-4a. Total light extinction trends for eastern Class I areas.

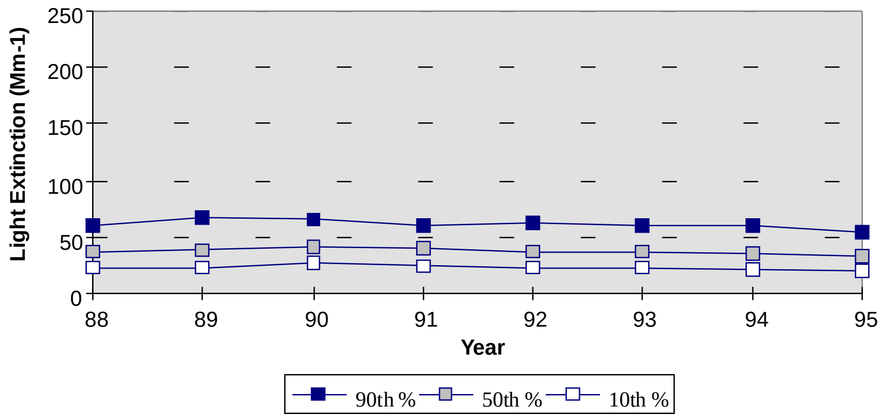


Figure 3-4b. Total light extinction trends for western Class I areas.

Current Conditions

On an annual average basis, natural visibility conditions have been estimated at approximately 80–90 miles in the East and up to 140 miles in the West.[3] Natural visibility varies by region primarily because of higher estimated background levels of $PM_{2.5}$ particles in the East, and the more significant effect of relative humidity on particle concentrations in the East than in the West. Current annual average conditions range from about 18–40 miles in the rural East and about 35–90 miles in the rural West.

Figure 3-8 illustrates annual average visibility impairment in terms of light extinction captured at IMPROVE sites between 1992 and 1995. The pie charts show the relative contribution of different particle constituents to visibility impairment. Annual average total light extinction due to these particles is indicated by the value next to each pie and by the size of each pie.[4]

Figure 3-8 also shows that visibility impairment is generally greater in the rural East compared to most of the West. In the rural East, sulfates account for about 50–70 percent of annual average light extinction. Sulfate plays a particularly significant role in the humid summer months, most notably in the Appalachian, northeast, and mid-south regions. Nitrates and organic and elemental carbon all account for between 10–15 percent of total light extinction in most Eastern locations.

In the rural West, sulfates also play a significant role, accounting for about 25–40 percent of total light extinction in most regions. Sulfates, however, account for over 50 percent of annual average light extinction in the Cascades of Oregon. Organic carbon typically is responsible for 15–35 percent of total light extinction in the rural West, elemental carbon (absorption) accounts

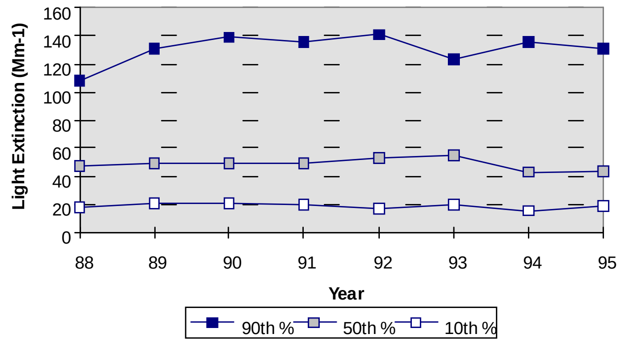


Figure 3-5a. Light extinction due to sulfate in eastern Class I areas.

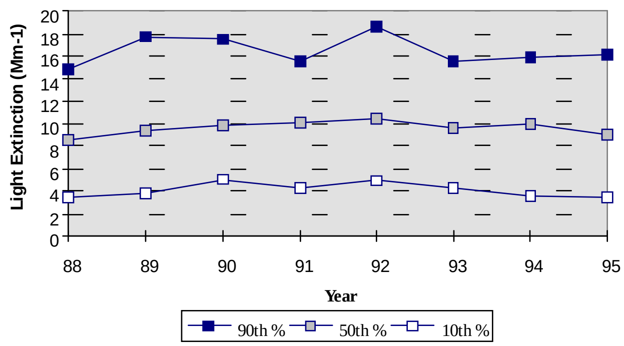


Figure 3-5b. Light extinction due to sulfate in western Class I areas.

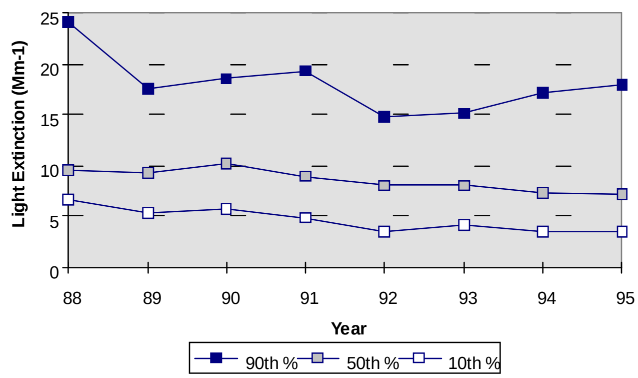


Figure 3-6a. Light extinction due to organic carbon in eastern Class I areas.

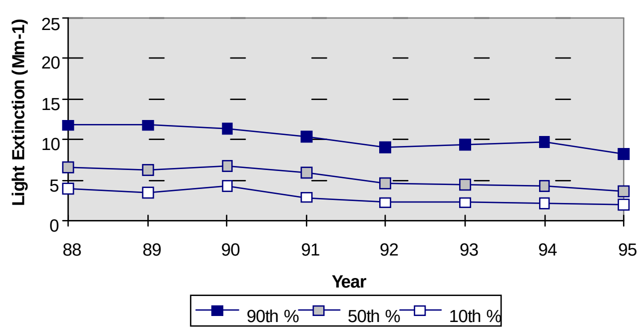


Figure 3-6b. Light extinction due to organic carbon in western Class I areas.

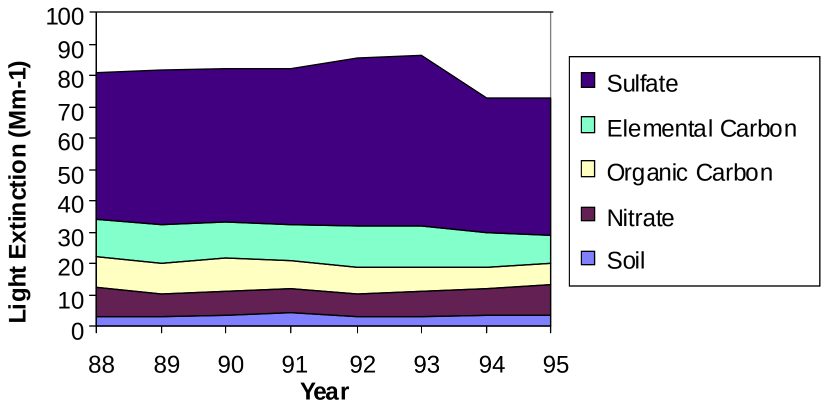


Figure 3-7a. Average aerosol light extinction in eastern Class I areas.

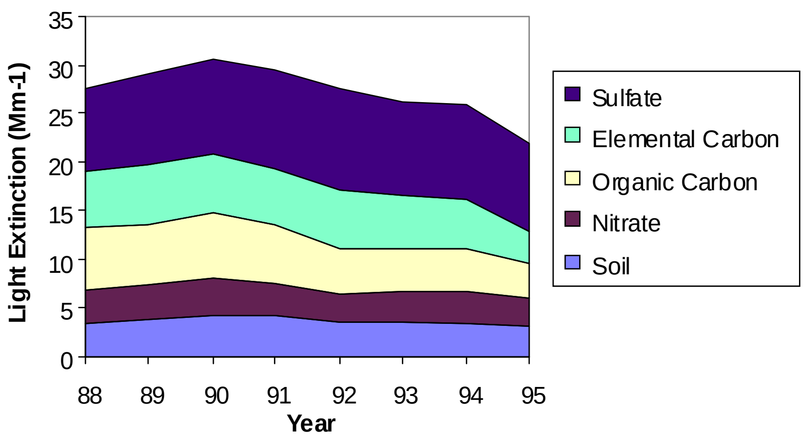


Figure 3-7b. Average aerosol light extinction in western Class I areas.

for about 15–25 percent, and soil dust (coarse PM) accounts for about 10–20 percent. Nitrates typically account for less than 10 percent of total light extinction in western locations, except in the southern California region, where it accounts for almost 40 percent.

Figure 3-9 also illustrates annual average visibility impairment from IMPROVE data for 1992–1995, expressed in deciviews.[4] Note that the deciview scale is more compressed than the scale for visual range or light extinction with larger values representing greater visibility degradation. Most of the sites in the intermountain West and Colorado Plateau have annual impairment of 12 deciviews or less, whereas many rural locations in the East have values exceeding 23 deciviews.

One key to understanding visibility effects is understanding that the same amount of pollution can have dramatically different effects on visibility depending on existing conditions. Most importantly, visibility in cleaner environments is more sensitive to increases in $PM_{2.5}$ particle concentrations than visibility in more polluted areas. This principle is illustrated in Figure 3-10, which characterizes visibility at Shenandoah National Park under a range of conditions.[5] A clear day at Shenandoah can be represented by a visual range of 80 miles, with conditions approximating naturally-occurring visibility (i.e., without pollution created by human activities). An average day at Shenandoah is represented by a visual range of 18 miles, and is the result of an additional 10µg / m^3 of fine particles in the atmosphere. The two bottom scenes, with visual ranges of eight and six miles respectively, illustrate that the perceived change in visibility due to an additional 10µg / m^3 of fine particles to an already degraded atmosphere is much less perceptible than adding this amount to a clean atmosphere. Thus, to achieve a given level of perceived visibility improvement, a larger reduction in fine particle concentrations is needed in more polluted areas. Conversely, a small amount of pollution in a clean area can dramatically decrease visibility.

Programs to Improve Visibility

In the recent review of the particulate matter NAAQS, EPA concluded that the most appropriate way of addressing visibility effects associated with PM was to establish secondary standards for PM equivalent to the suite of primary standards in conjunction with establishment of a new regional haze program. In July 1997, EPA proposed a new regional haze program to address visibility impairment in national parks and wilderness areas caused by numerous sources located over broad regions. The proposed program takes into consideration recommendations from the National Academy of Sciences, the Grand Canyon Visibility Transport Commission, and a Federal Advisory Committee on Ozone, Particulate Matter, and Regional Haze Implementation

Programs. The proposal lays out a framework within which states are to conduct regional planning and develop implementation plans which are to achieve "reasonable progress" toward the national visibility goal of no human-caused impairment. Because of the common precursors and the regional nature of the ozone, PM, and regional haze problems, EPA is developing these implementation programs together to integrate future planning and control strategy efforts to the greatest extent possible. Implementation of the NAAQS in conjunction with a future regional haze program is anticipated to improve visibility in urban and rural areas across the country.

Other air quality programs are expected to lead to emissions reductions that will improve visibility in certain regions of the country. The Acid Rain program is designed to achieve significant reductions in sulfur oxide emissions, which is expected to reduce sulfate haze particularly in the eastern United States. Additional control programs on sources of nitrogen oxides to reduce formation of ozone can also improve regional visibility conditions. In addition, the NAAQS, mobile source, and woodstove programs to reduce fuel combustion and soot emissions can benefit areas adversely impacted by visibility impairment due to sources of organic and elemental carbon.

Table 3-1. Summary of Class I Area Trend Analysis

PARAMETER	Sites with Significant Downward Trend	Sites with Significant Upward Trend
Deciviews, average days	8	0
Deciviews, clean days	11	0
Deciviews, hazy days	5	0
Extinction due to sulfate, average days	1	0
Extinction due to sulfate, clean days	1	0
Extinction due to sulfate, hazy days	0	0
Extinction due to organic carbon, average days	26	0
Extinction due to organic carbon, clean days	27	0
Extinction due to organic carbon, hazy days	12	0

Table 3-2. IMPROVE Sites With Potential Upward Trends

Best Days (10th Percentile)	Median Days (50th Percentile)	Worst Days (90th Percentile)
Weminuche	Crater Lake	Acadia
	Great Smoky Mountains	Badlands
	Mount Rainier	Big Bend
	Washington, DC	Chiricahua
	Yosemite	Crater Lake
		Glacier
		Great Smoky Mountains
		Point Reyes
		Shenandoah
		Washington

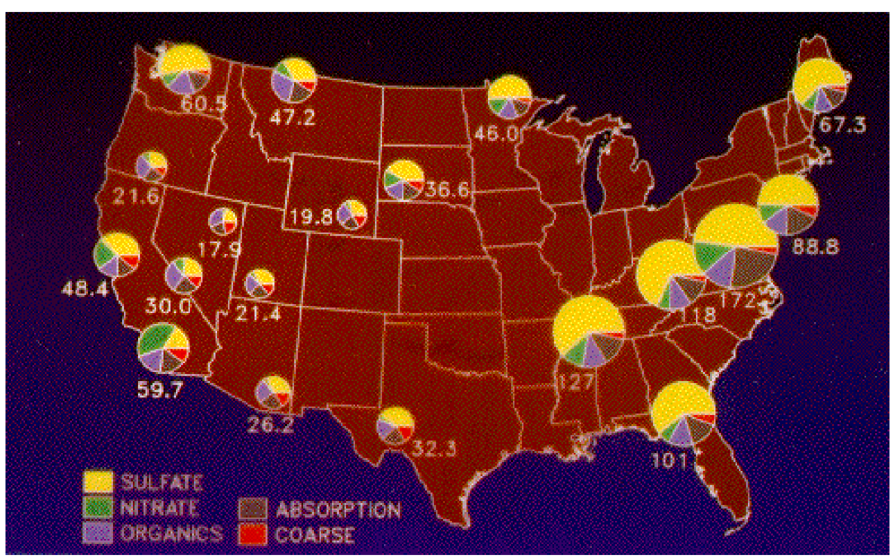


Figure 3-8. Annual average light extinction (Mm^{-1}), 1992–1995 IMPROVE data.

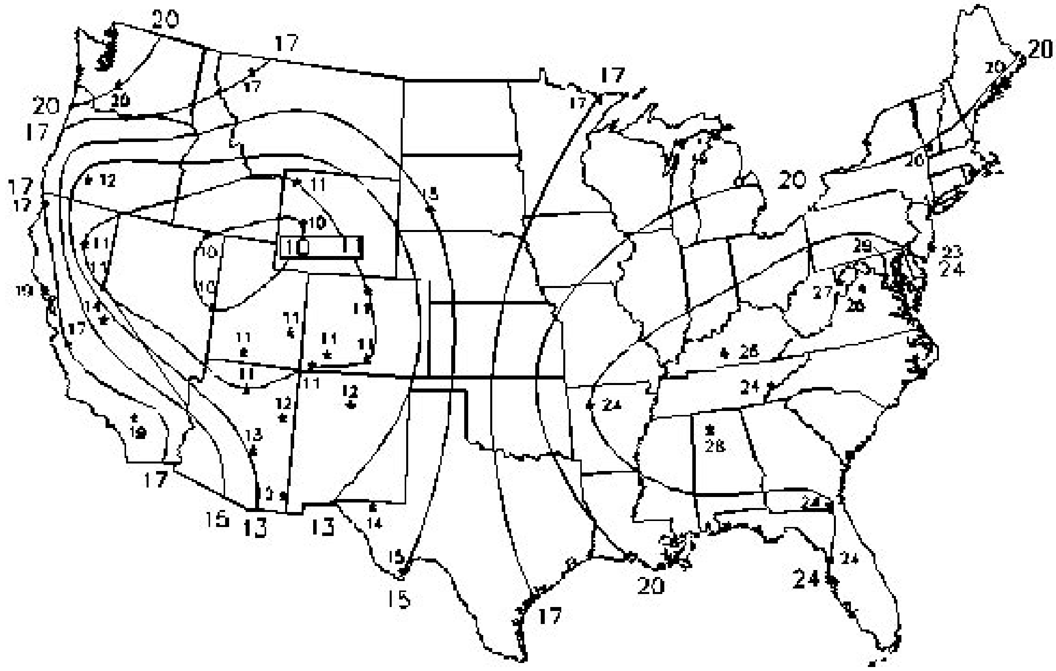


Figure 3-9. Annual average visibility impairment in deciviews relative to pristine conditions of deciviews = 0, 1992–1995 IMPROVE data.

Figure 3-10. Shenandoah National Park on clear and hazy days, and the effect of adding 10 $\mu g/m^3$ fine particles to each.

References

1. Images were created with WinHaze Software, John Molenar, Air Resource Specialists, Inc., Fort Collins, Colorado 80525.

2. R.B. Husar, J.B. Elkins, W.E. Wilson, "U.S. Visibility Trends, 1906–1992," Air and Waste Management Association 87th Annual Meeting and Exhibition, Cincinnati, OH, 1994.

3. Irving, Patricia M., e.d., *Acid Deposition: State of Science and Technology*, Volume III, Terrestrial, Materials, Health, and Visibility Effects, The U.S. National Acid Precipitation Assessment Program, Chapter 24, page 24–76.

4. Sisler, J. *Spatial and Seasonal Patterns and Long-Term Variability of the Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network*. Colorado State University, Cooperative Institute for Research in the Atmosphere. Fort Collins, CO., 1996.

5. Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO.